APPENDIX A: CONDUCTED VERSUS RADIATED PATH MEASUREMENTS

A.1 Overview

As illustrated in Figure A.1.1, there are two possible methods for performing radio interference measurements; one is conducted and the other is radiated. While radiated measurements have the advantage of simulating real world conditions, conducted measurements have the distinct advantage of being able to test under highly controlled conditions. The latter were chosen as the preferred method for performing the UWB/GPS interference measurements at the Institute for Telecommunication Sciences (ITS). To impute validity for the measurements, it is imperative, however, that the effects on the signal within the frequency band of interest be nearly identical, whether conducted or radiated. As the UWB signal proceeds from A to B or from A to C (shown in Figure A.1.1), the temporal characteristics of the pulse change due to various effects on the magnitude and phase across the frequency band. Some of this is expected because filtering, attenuation, and amplification occur along the path. The phase and magnitude of the signal are represented by $X(j\omega)$ at the pulse generator output connector, and $Y_1(j\omega)$ and $Y_2(j\omega)$ at the output of the GPS antenna terminal for the radiated path and the output of the LNA for the conducted path respectively (where $X(j\omega)$, $Y_1(j\omega)$, and $Y_2(j\omega)$ are the Fourier transform of the time-domain signal at the respective locations – A, B, and C). The transfer functions of the different paths are represented by $H(j\omega)$ and $G(j\omega)$, whereby $H(j\omega) = Y_1(j\omega) / X(j\omega)$ and $G(j\omega) = Y_2(j\omega) / X(j\omega)$. Ideally, $H(j\omega)$ and $G(j\omega)$ should be identical across the frequency band of interest.

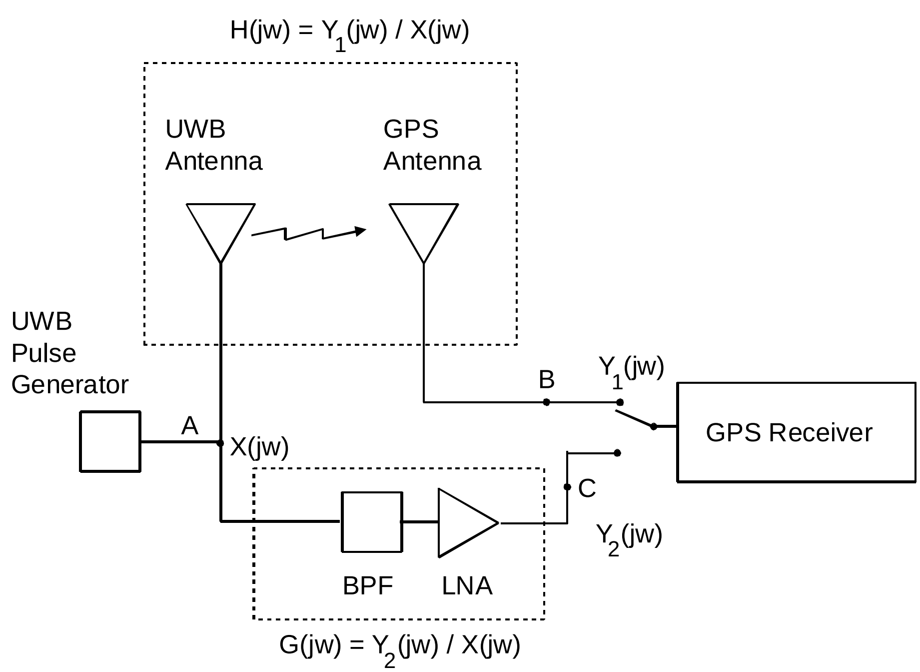

Figure A.1.1. Conducted versus radiated measurement concept.

To help match the transfer functions between the two paths, a band-pass filter (BPF) and low-noise (LNA) amplifier of bandwidth and gain, equivalent to that of the GPS antenna, were placed in the conducted path for all interference measurements. The UWB antenna is assumed to have a much wider bandwidth, making it less likely to contribute to narrowing of the bandwidth and therefore, does not require a filter to emulate its bandwidth characteristics.

Because, in real world applications, both UWB antennas and GPS antennas are used to transmit and receive pulsed or digital signals, it is assumed that the magnitude and phase distortion is minimal over the L1 band, and therefore, there should be little difference in signals (conducted or radiated) as seen in the L1 band. To verify these assumptions, measurements described herein were performed to determine the degree to which signals passed through the two paths, conducted and radiated, are likely to be the same. This was accomplished by measuring temporal characteristics of the UWB signal at points A and B as represented in Figure A.1.1. The measurements include high speed digitization of a single pulse (to determine the transfer function of the radiated path by performing Fourier analysis), as well as multiple pulse acquisitions to compare APD characteristics at points A and B for four different pulse spacing modes.

A.2 Single Pulse Measurement

High speed digitization of UWB signals emitted from a Time Domain Corporation PG-2000 pulse generator was conducted by the National Institute for Standards and Technology (NIST) Radio-Frequency Technology Division in their Time-Domain Laboratory to obtain data that represents the radiated time-domain waveform. The goal of these measurements was to capture a detailed view of a single pulse using a single-event transient digitizer capable of achieving very high sample rates. The digitizer used in this study possesses a bandwidth of 4.5 GHz with a maximum of 1,024 samples in a single shot and is designed to perform high fidelity measurements on a single pulse.

Conducted measurements were performed using the test fixture shown in Figure A.2.1. The RF output of the UWB device-under-test was connected using a coaxial transmission line to an attenuator, used to prevent overloading and damage to the measurement device from an overly strong signal level. The signal was then split into two equal amplitude levels and fed into a trigger port and a signal port on the transient digitizer.

Radiated measurements were performed using the test fixture shown in Figure A.2.2. Data was acquired in the NIST anechoic chamber using two different antennas: a UWB antenna (transmit) supplied by the manufacturer of the pulse generator, and a GPS antenna (receive) supplied with one of the receivers under test. The signal was split into two equal amplitude levels and fed into a trigger port and a signal port on the high speed transient digitizer.

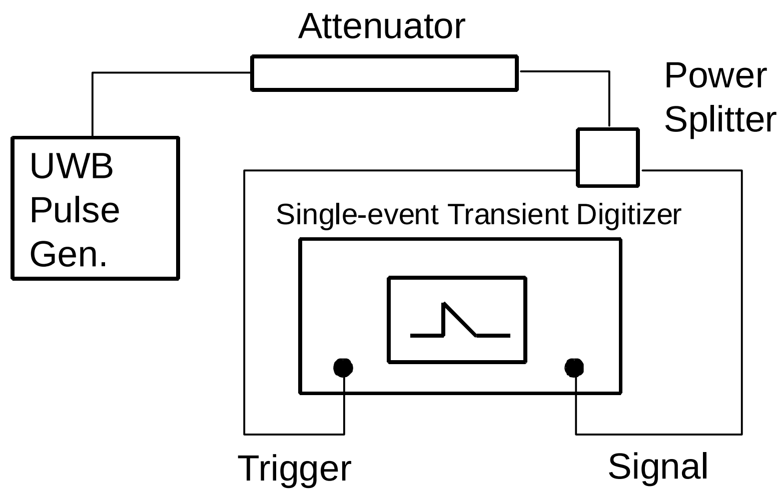

Figure A.2.1 Conducted measurement test setup.

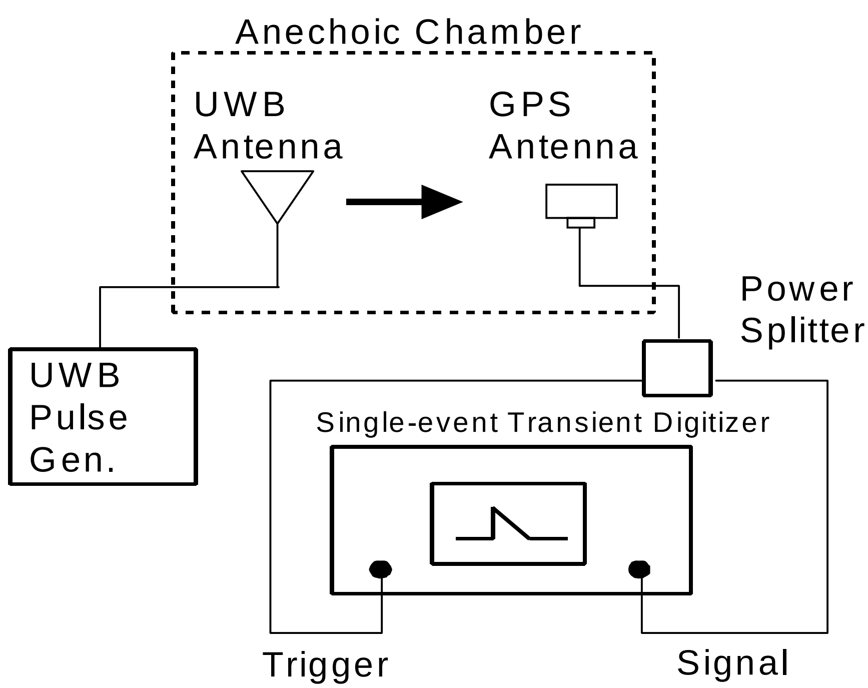

Figure A.2.2. Radiated measurement test setup.

The acquired pulses were processed to derive the complex transfer function for the radiated path ($H(j\omega)$). This was accomplished by performing a Fourier transform on the digitized time-domain radiated and conducted pulses to give $Y_1(j\omega)$ and $X(j\omega)$ respectively. To increase the frequency resolution to 150 kHz, each digitized pulse was padded with zeros (prior to applying the Fourier transform) to give a total sample size of 131,072 points. This is justified by the fact that the pulse goes to zero after full decay, and by padding with zeros, we are adding additional information that we know to be true. The complex transfer function of the radiated path was then determined by dividing $Y_1(j\omega)$ by $X(j\omega)$ to provide magnitude and group delay information across the band of interest. Since the transfer function of path A to C ($G(j\omega)$ in Figure A.1.1) is determined primarily by the inline bandpass filter (used during interference measurements), we can compare the effects of the two different paths by comparing $H(j\omega)$ (the transfer function of the radiated path) with $G(j\omega)$ (the transfer function of the filter). Figures A.2.4 through A.2.13 show the magnitude and group delay for the radiated path and for each of the inline filters used (filters F1 - F4 described in Appendix A). While there are significant differences at wider bandwidths, there is very little difference in the 20-MHz bandwidth centered at L1.

In addition to the magnitude and group delay characteristics, we can further compare the time-domain characteristics of the two different paths (A to B and A to C) by multiplying both $Y_1(j\omega)$, and $Y_2(j\omega)$ by the transfer function of a narrower filter (e.g. a 24-MHz bandpass filter) and applying the inverse Fourier transform. Figure A.2.3 illustrates the different paths used in the UWB/GPS interference measurements, each having their own transfer function. Path AB represents the radiated path, going from the UWB pulse generator to the output of the GPS antenna. Path AC represents the conducted path from the UWB pulse generator to receiver 2, and path AD for receiver 1. Assuming a maximum bandwidth of 24 MHz along each paths, as the signal ultimately passes through the preselector filter of the GPS receiver, we can compare the time-domain response at the output of each path (represented by paths ABF, ACF, and ADF). This is accomplished by multiplying the Fourier transform of the input signal at point A by the transfer function of each component along the chain (whether it be the two antennas, or inline filters) and then performing the inverse Fourier transform on the result. This is done for each of the four paths. Figure A.2.14 shows two pulses: one at the output of the UWB pulse generator and the other at the output of the GPS antenna (via the radiated path). Figure A.2.15 shows the simulated pulses at the output of each of the three paths (ABF, ACF, and ADF). While the pulses at various points along the chain (at different bandwidths) may be quite different, we can see that for the output at the end of each path, when limited in bandwidth by the same 24-MHz filter, there is very little difference in the time-domain characteristics.

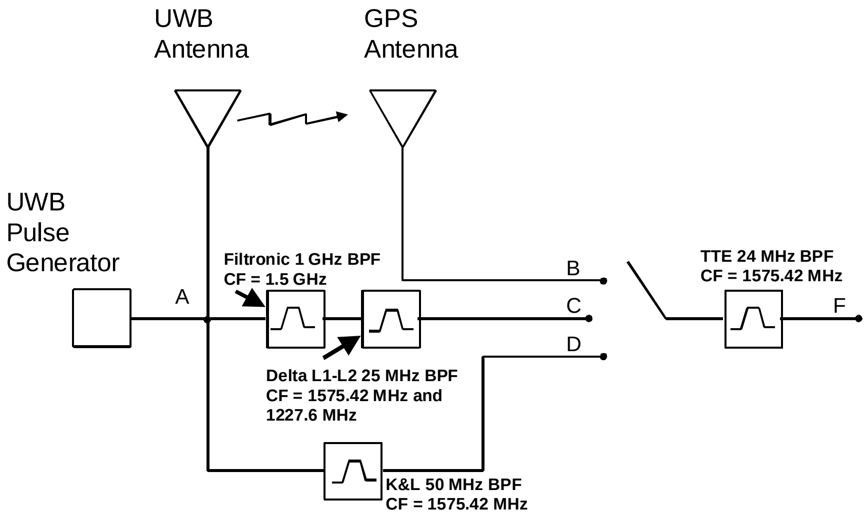

Figure A.2.3. Filter specifications for the different measurement paths.

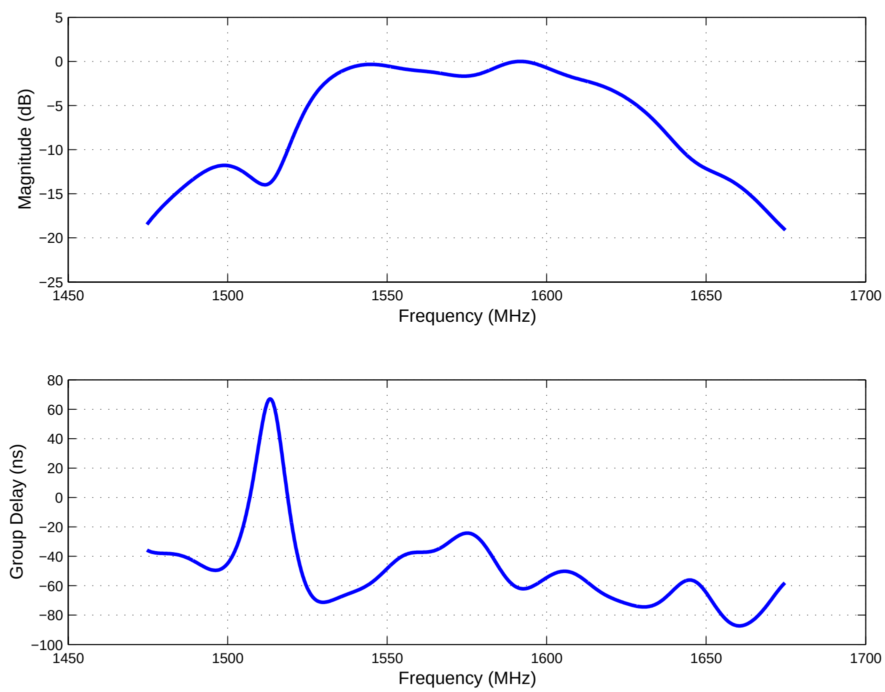

Figure A.2.4. Transfer function magnitude and group delay for radiated path - 1475 MHz to 1675 MHz.

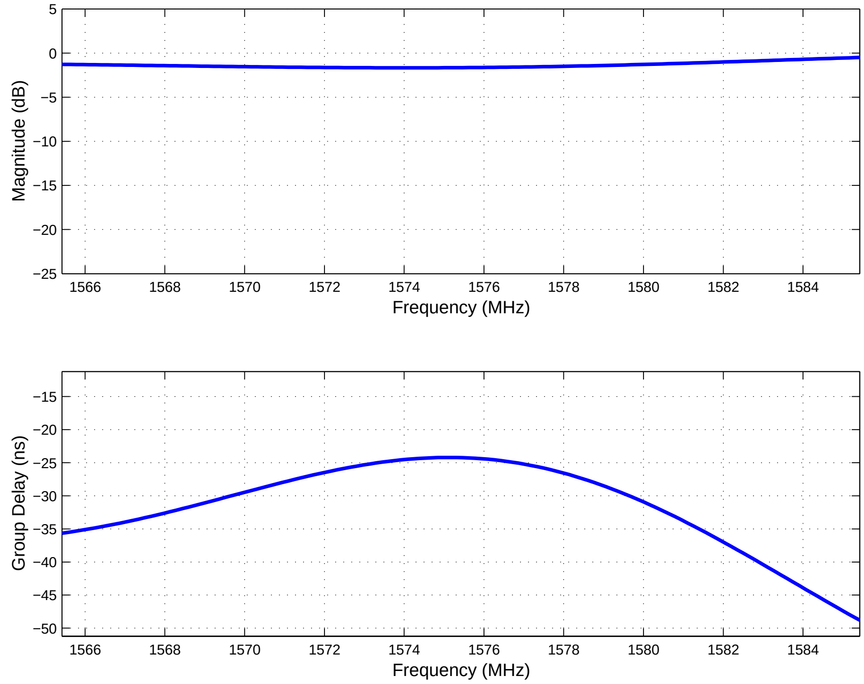

Figure A.2.5. Transfer function magnitude and group delay for radiated path - 1565 MHz to 1585 MHz.

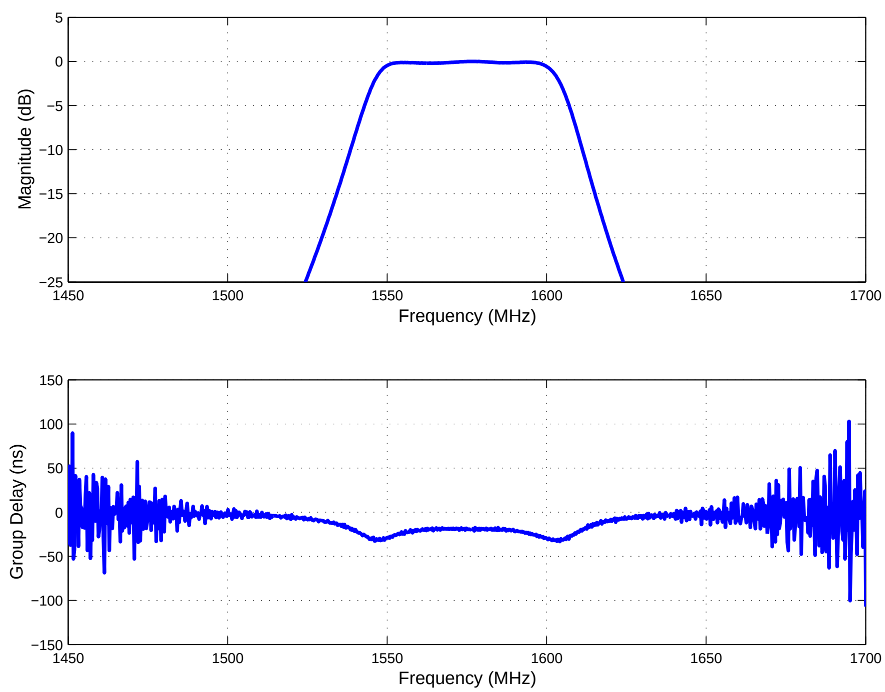

Figure A.2.6. Transfer function magnitude and group delay for filter F3 - 1475 MHz to 1675 MHz.

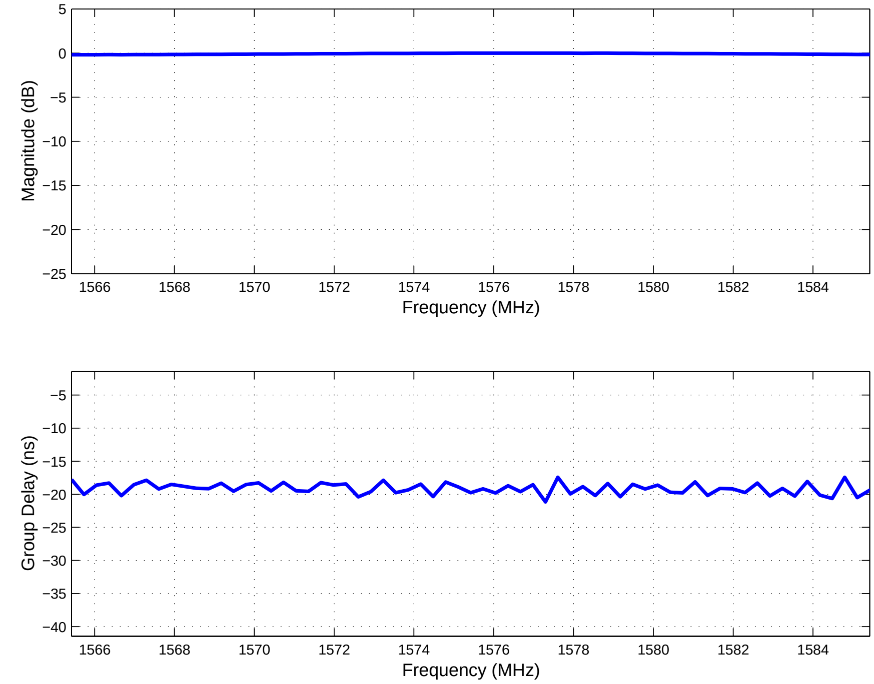

Figure A.2.7. Transfer function magnitude and group delay for filter F3 - 1565 MHz to 1585 MHz.

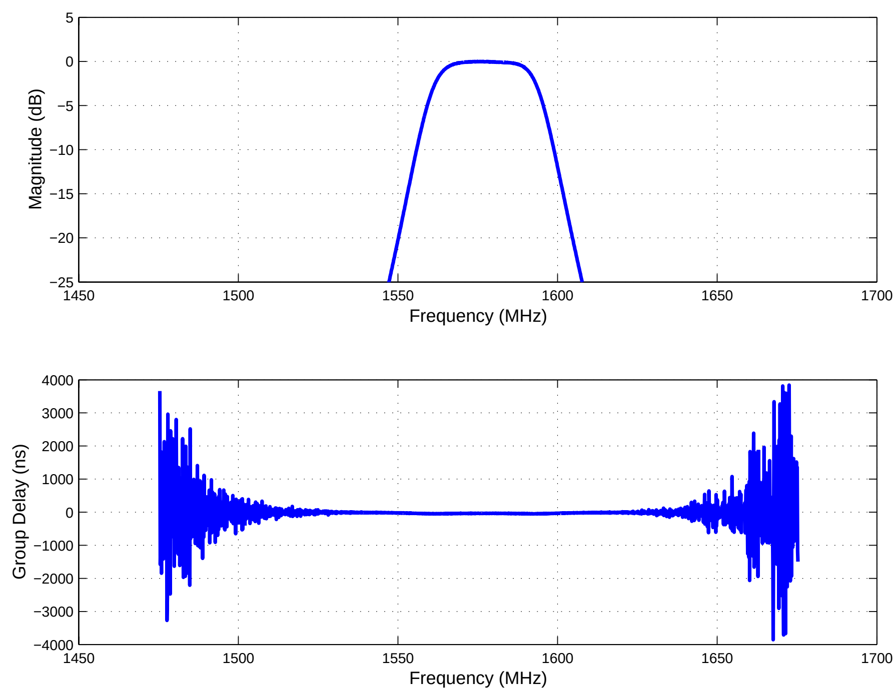

Figure A.2.8. Transfer function magnitude and group delay for filter F1 - 1475 MHz to 1675 MHz.

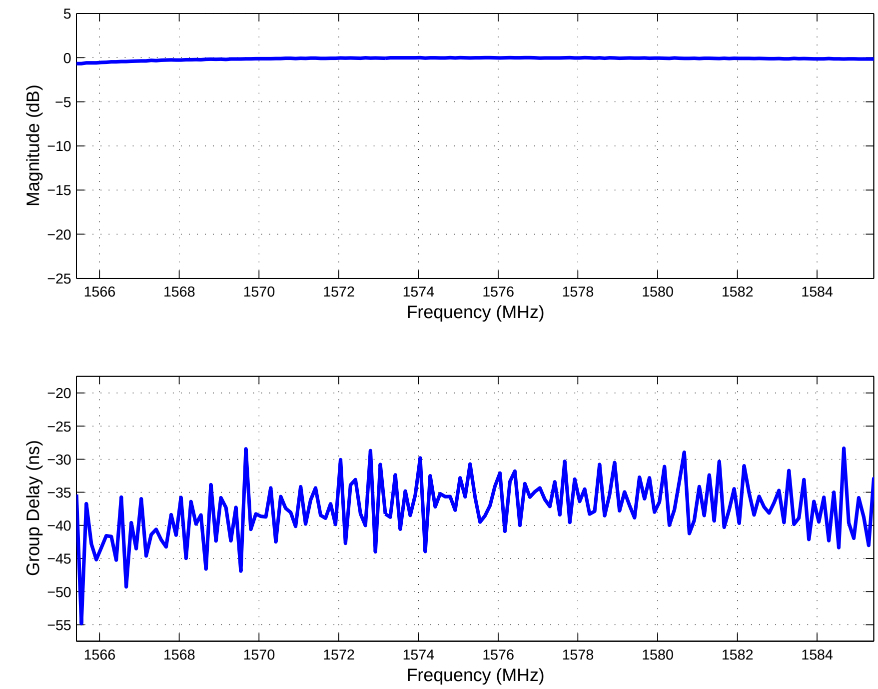

Figure A.2.9. Transfer function magnitude and group delay for filter F1 - 1565 MHz to 1585 MHz.

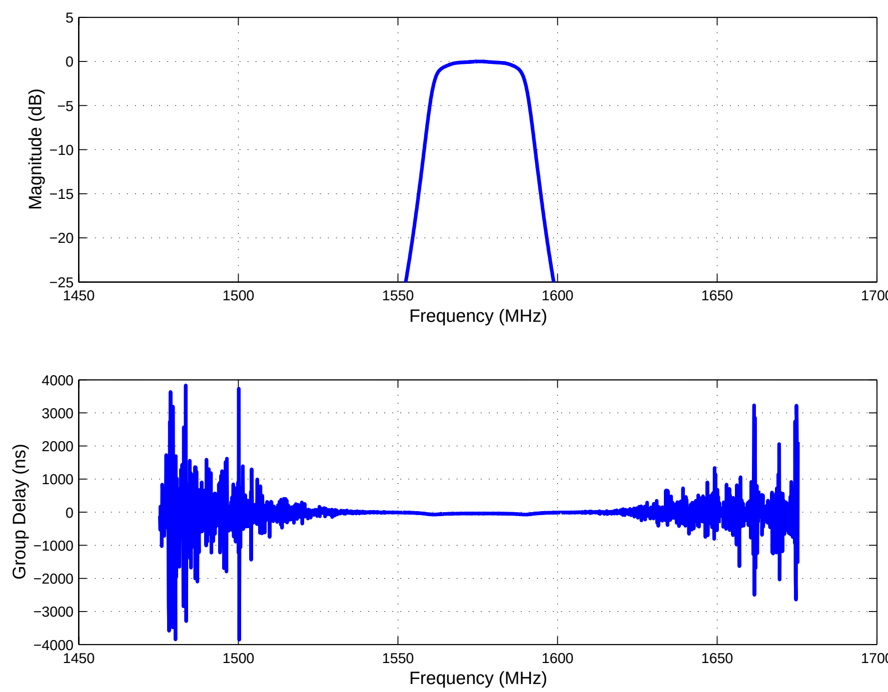

Figure A.2.10. Transfer function magnitude and group delay for filter F4 - 1475 MHz to 1675 MHz.

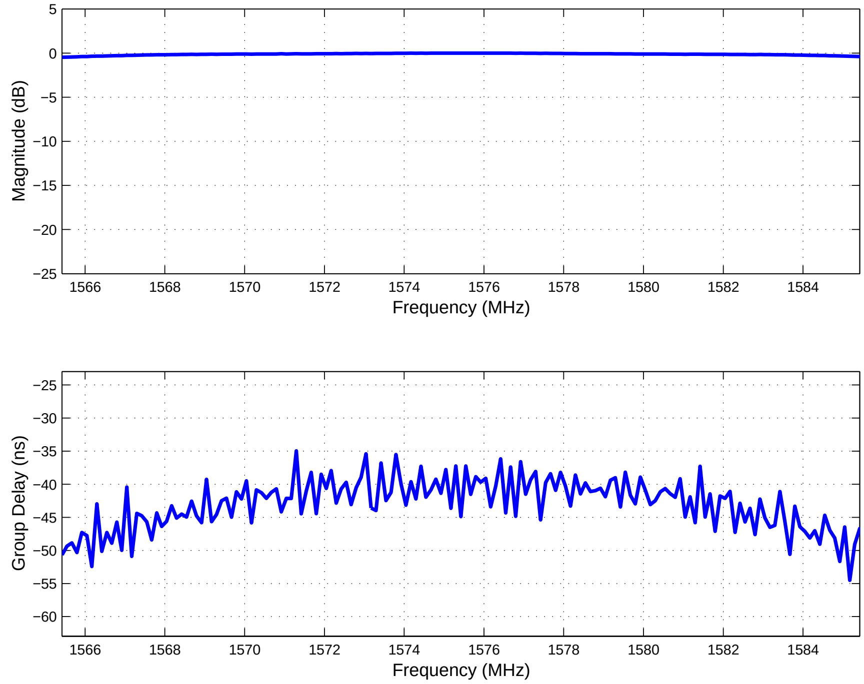

Figure A.2.11. Transfer function magnitude and group delay for filter F4 - 1565 MHz to 1585 MHz.

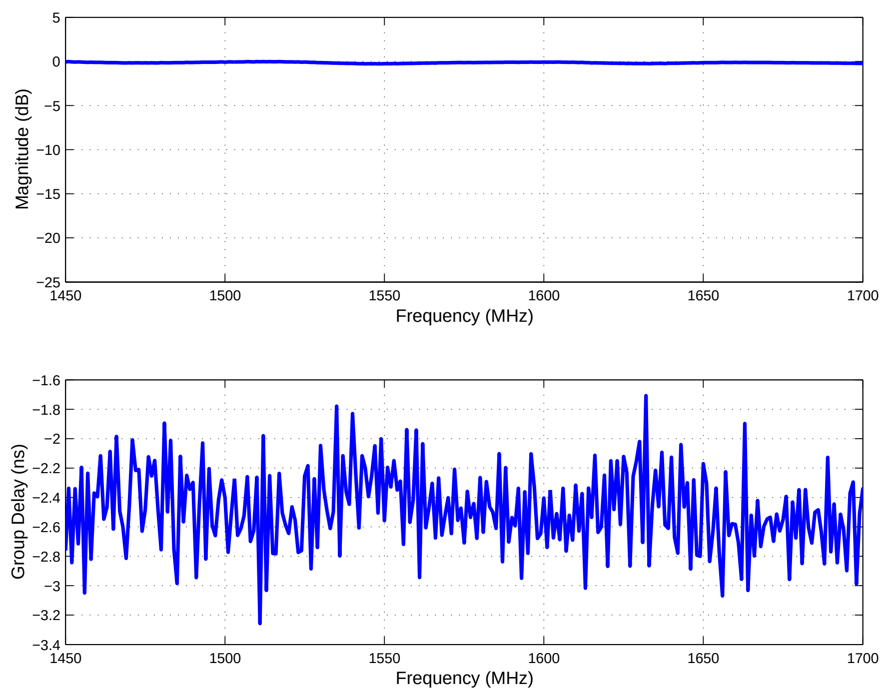

Figure A.2.12. Transfer function magnitude and group delay for filter F2 - 1475 MHz to 1675 MHz.

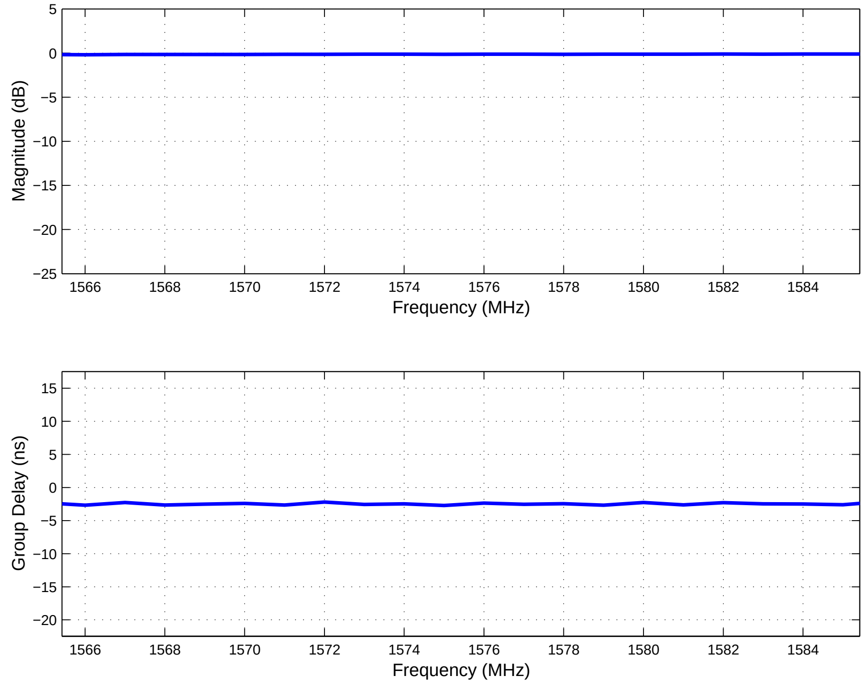

Figure A.2.13. Transfer function magnitude and group delay for filter F2 - 1565 MHz to 1585 MHz.

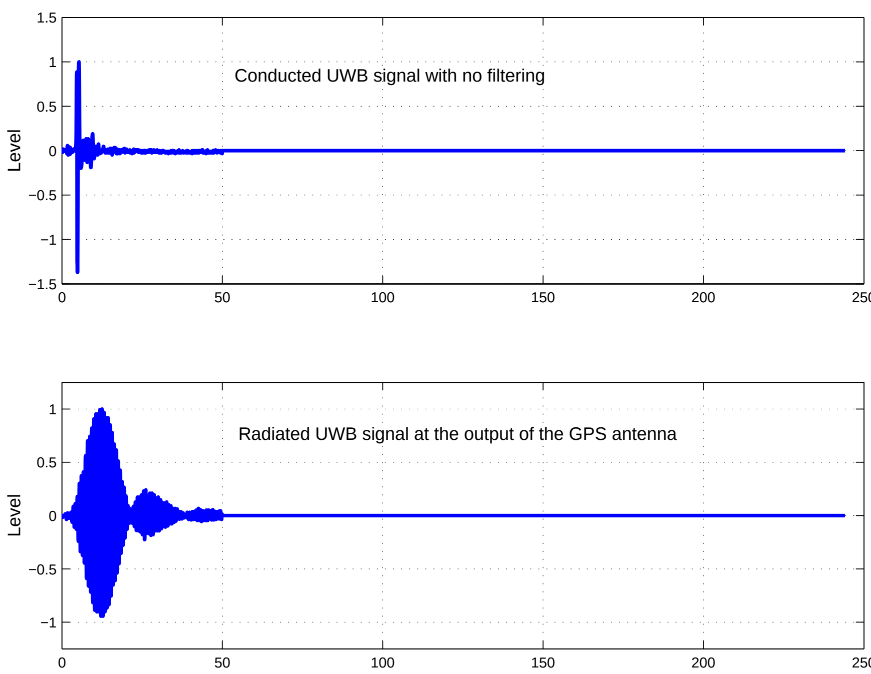

Figure A.2.14. Pulse characteristics - conducted and radiated. (Levels are normalized to peak voltage.)

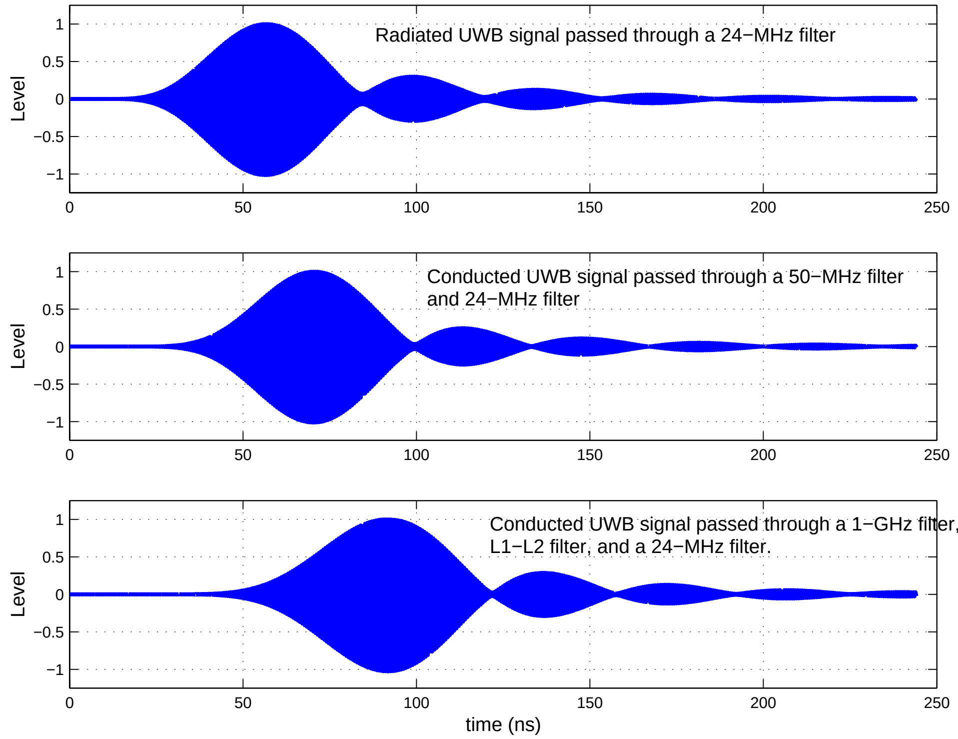

Figure A.2.15. Pulse characteristics through different measurement paths. (Levels are normalized to peak voltage.)

A.3 Multiple Pulse Measurement

Multiple pulse measurements were performed to determine the degree of signal alteration with regard to APDs, when the signal is radiated. While it is possible to have two remarkably different signals with the same amplitude distribution, if a signal, radiated and conducted, has the same amplitude distribution for the two different paths, the time-domain shape is likely to be very similar. For this reason, APD measurements were performed for two different bandwidths (3 MHz and 20 MHz centered at L1) using four different UWB signals. Results of these measurements (see Figures A.3.1 through A.3.8) show very little difference between the radiated and conducted path for the bandwidths of interest.

Data, for both conducted and radiated paths, was acquired and processed using techniques described in NTIA Report 01-383 [1].

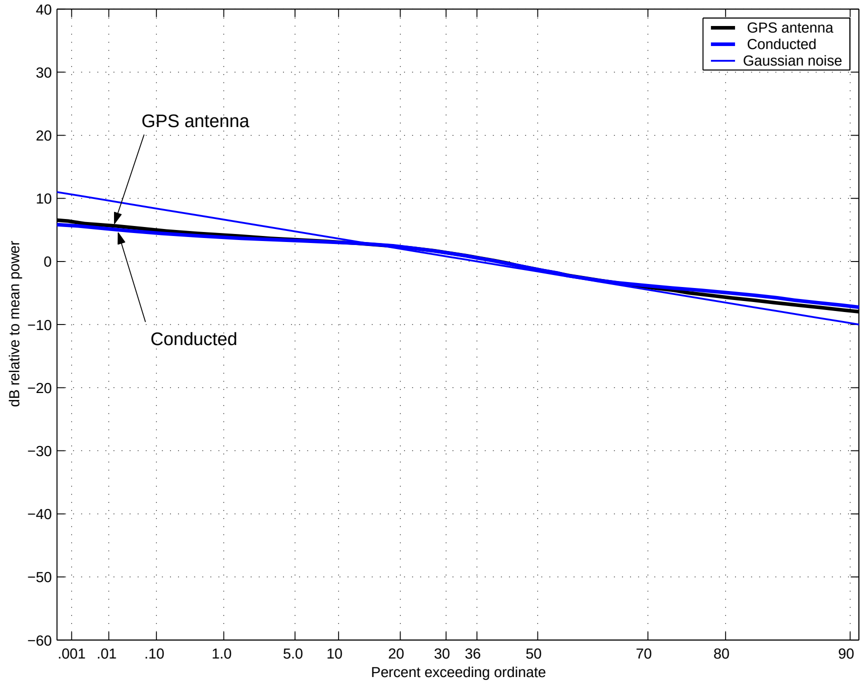

Figure A.3.1. Radiated vs. conducted APDs of 2%-RRD UWB signals (3-MHz PRF, no gating) measured in a 3-MHz bandwidth.

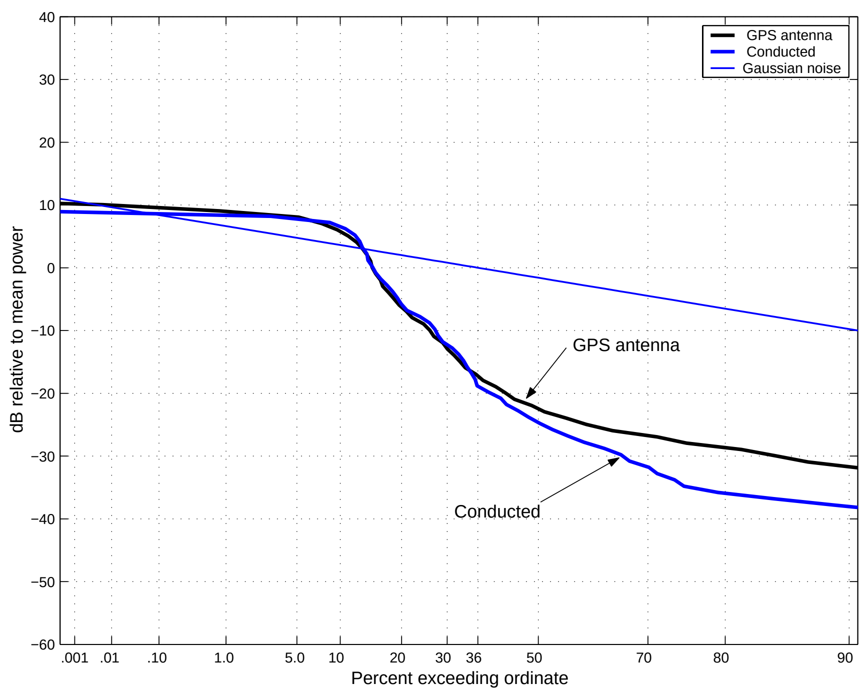

Figure A.3.2. Radiated vs. conducted APDs of 2%-RRD UWB signals (3-MHz PRF, no gating) measured in a 20-MHz bandwidth.

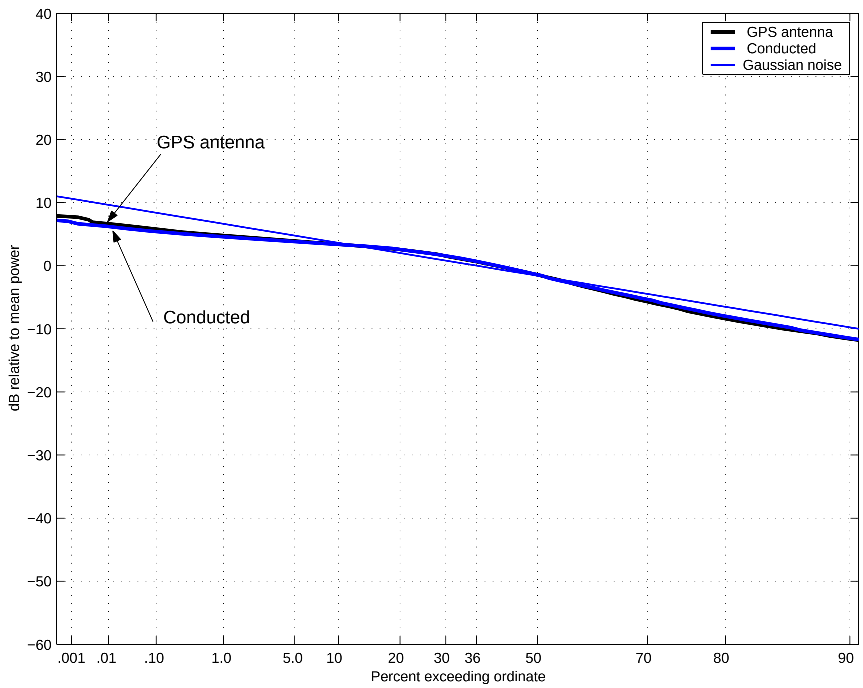

Figure A.3.3. Radiated vs. conducted APDs of 50%-ARD UWB signals (3-MHz PRF, no gating) measured in a 3-MHz bandwidth.

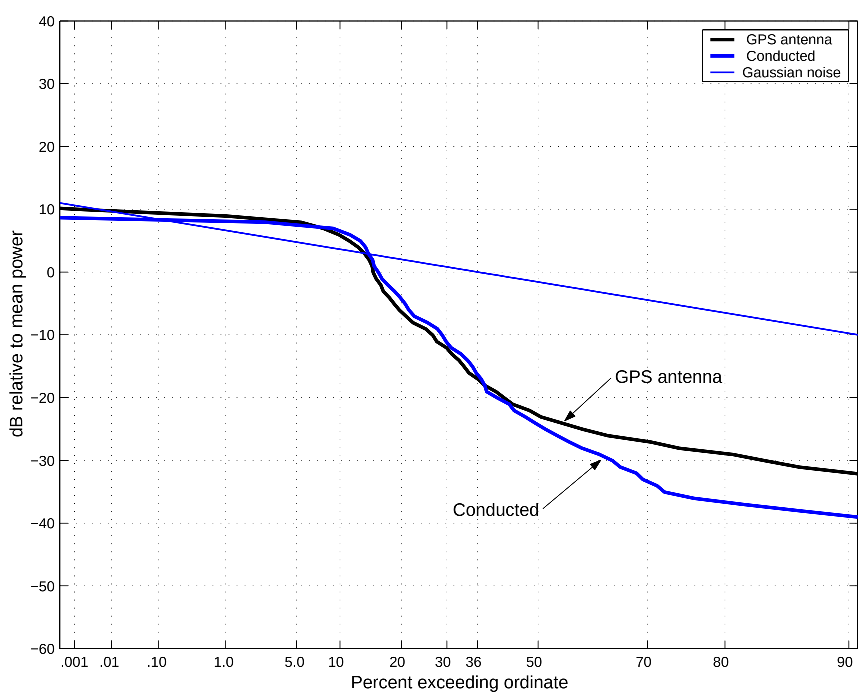

Figure A.3.4. Radiated vs. conducted APDs of 50%-ARD UWB signals (3-MHz PRF, no gating) measured in a 20-MHz bandwidth.

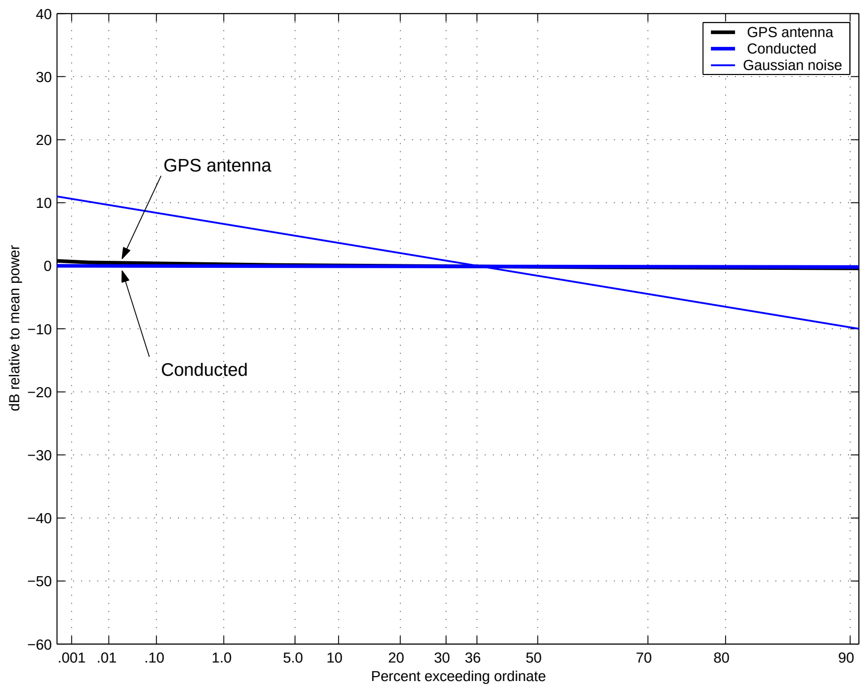

Figure A.3.5. Radiated vs. conducted APDs of UPS UWB signals (10-MHz PRF, no gating) measured in a 3-MHz bandwidth.

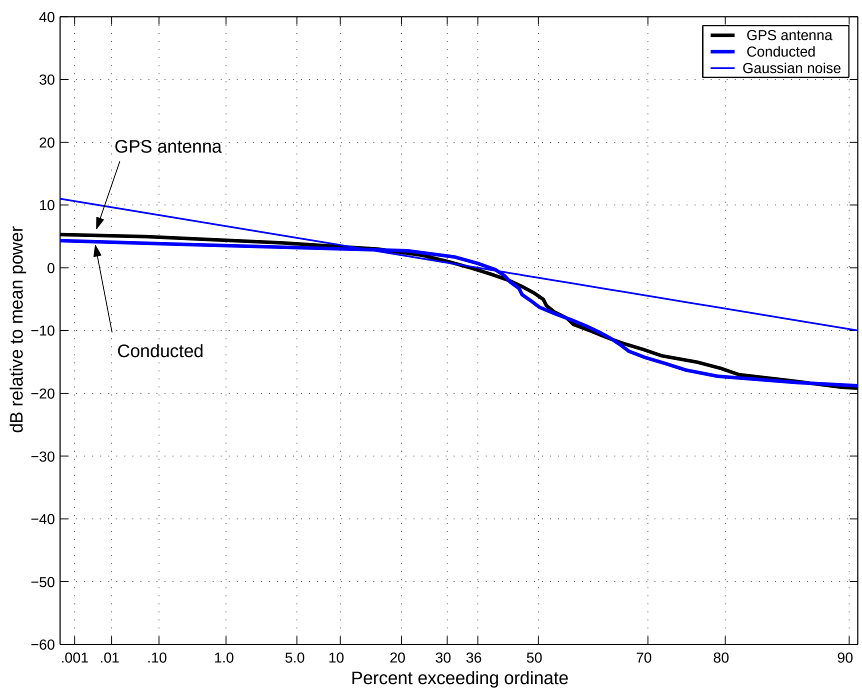

Figure A.3.6. Radiated vs. conducted APDs of UPS UWB signals (10-MHz PRF, no gating) measured in a 20-MHz bandwidth.

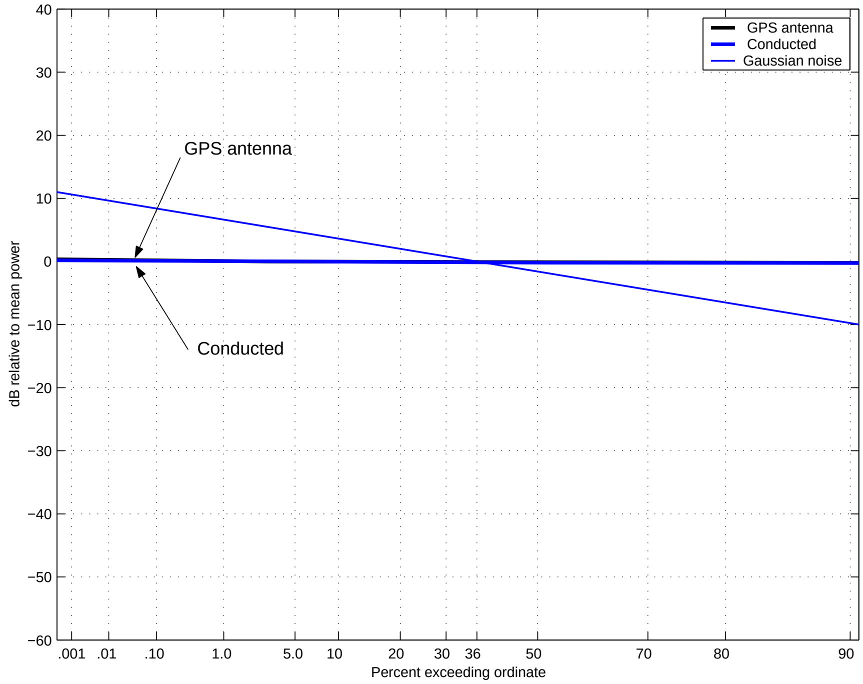

Figure A.3.7. Radiated vs. conducted APDs of UPS UWB signals (20-MHz PRF, no gating) measured in a 3-MHz bandwidth.

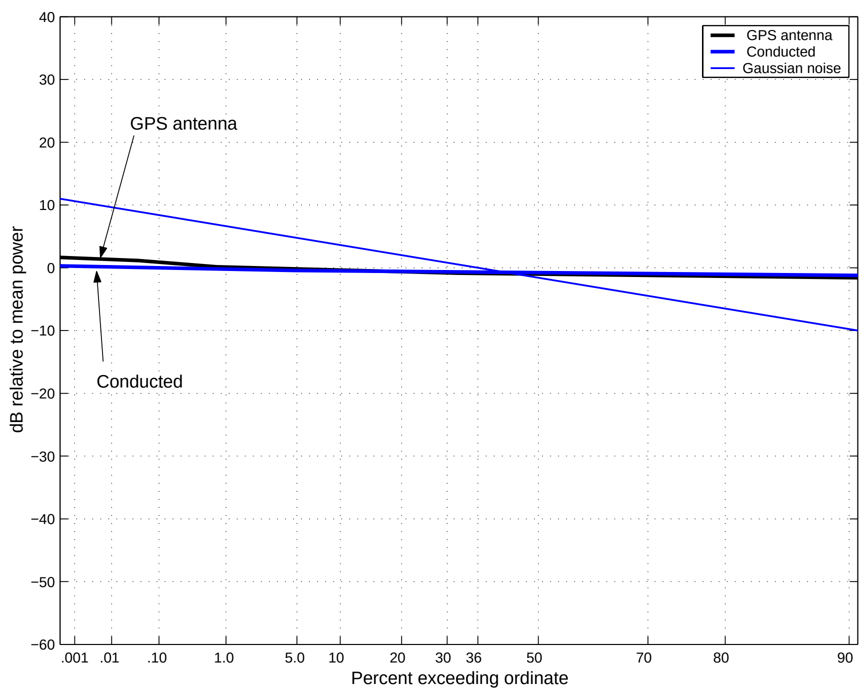

Figure A.3.8. Radiated vs. conducted APDs of UPS UWB signals (20-MHz PRF, no gating) measured in a 20-MHz bandwidth.

A.4 Conclusions

To reiterate what was discussed previously, it is necessary to verify that the conducted and radiated paths have nearly identical affects on the frequency and time-domain characteristics of the signal. Through the measurements described in this Appendix, it was shown that the magnitude and group delay characteristics, as well as the temporal characteristics (as shown through APDs time-domain pulse shapes) were similar whether radiated or conducted through a filtered path. The conclusion is that, while the GPS/UWB interference measurements were performed by transmitting signals through a conducted path, the effects should be no different than those measured during a radiated test (barring channel distortion such as multipath).

References

[1] W.A. Kissick, Ed., "The temporal and spectral characteristics of ultrawideband signals," NTIA Report 01-383, Jan. 2001.